

Introduction to



PROGRAM OVERVIEW

Swapn Chattopadhyay

CBP Review

March 24 & 25, 1997



On deeper examination, we find that most human endeavors are concerned with:

MANIPULATION, FOCUSSING and
TRANSMISSION of ENERGY and
INFORMATION

for various purposes relevant to the HUMAN
CONDITION and their lies, the critical
significance of the

ART and SCIENCE of
“BEAMS”



Advanced Accelerator Concepts '96
Granlibakken, Lake Tahoe, CA
10/12-18/96





Academic & Visiting Scientists

- Faculty Associates

- R. Falcone (lasers)
- J. Wurtele (beam physics)
- M. Shapiro (experimental laser-plasma detection)
- J. Siegriest (experimental laser-plasma detection)

- Visiting Scientists

- Y. Kishimoto, JAERI, Japan
- J. Koga, JAERI, Japan
- Y. Orlov, Cornell
- R. Ryne, LANL
- T. Tajima, UT Austin
- V. Telnov, BINP
- K. Yokoya, KEK

- Center Affiliates

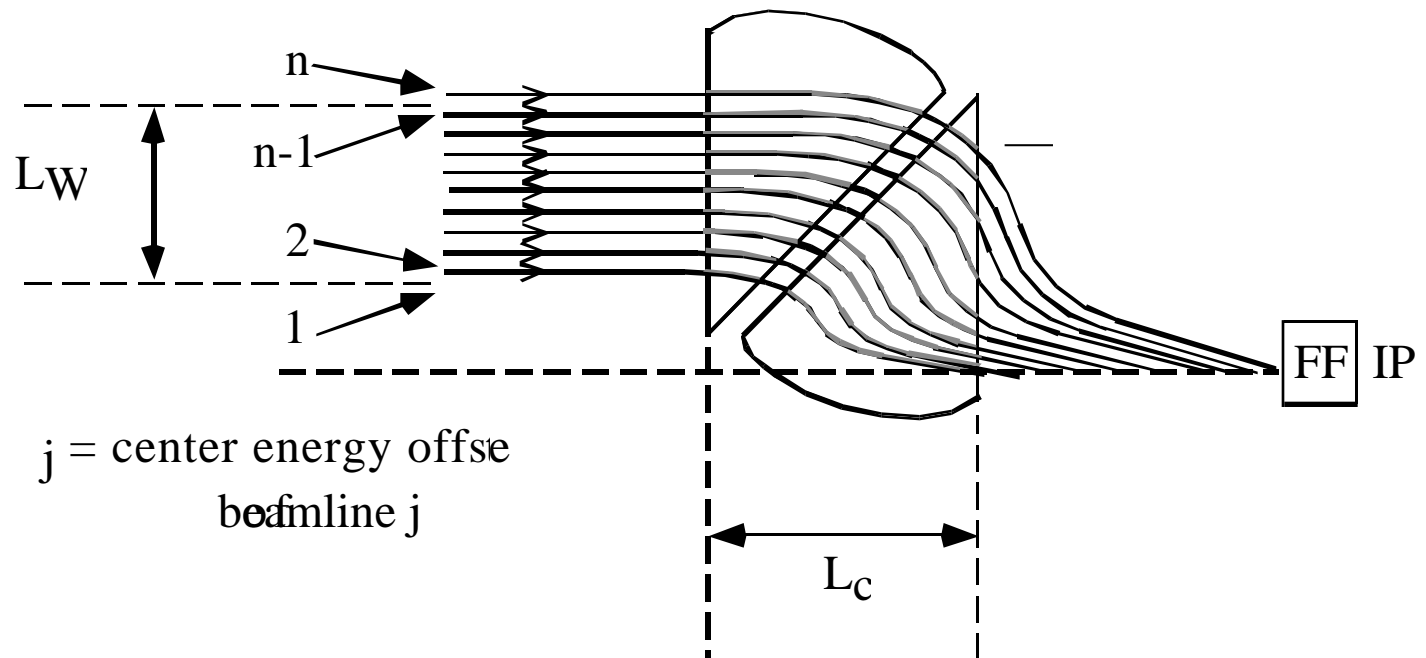
- W. Barletta
- R. Gough
- A. Jackson
- R. Keller
- C. Kim
- D. Robin
- R. Schoenlein
- C. Shank
- H. Nishimura

- Participating Guests

- Five Emeriti scientists (A. Garren, G. Lambertson, J. Peterson, F. Selph, F. Voelker)
- L. Schachinger



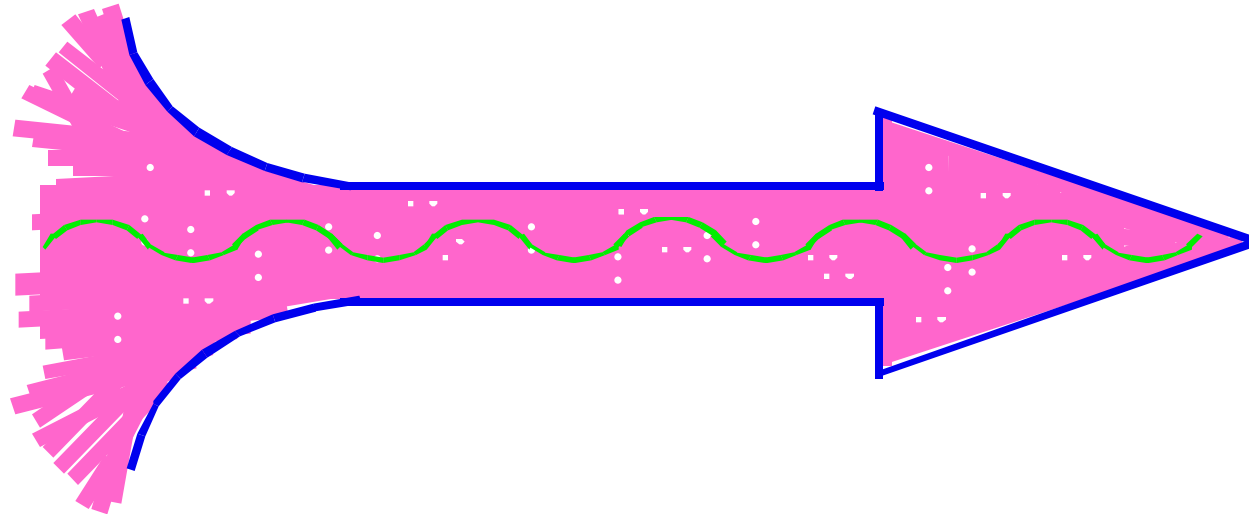
- Faraday Cup for Beam Instrumentation : W. Barry
- Wilson Prize in Accelerator Physics (APS) and
D. R. Nicholson Humanitarian Award (APS) : A. Sessler
- Halbach Prize: W. Leemans and R. Schoenlein and team
- JAERI, 1995 Distinguished Visiting Scientist : S. Chattopadhyay
- APS Fellowships
- 1997 International FEL Prize : K.-J. Kim





BEAMS

Directed and Focused Flow of Energy and Information



- Particles: electrons, protons, ions, ...
- Ultraviolet, Visible, Infrared, X-ray, Radio ; Lasers

BEAMS :

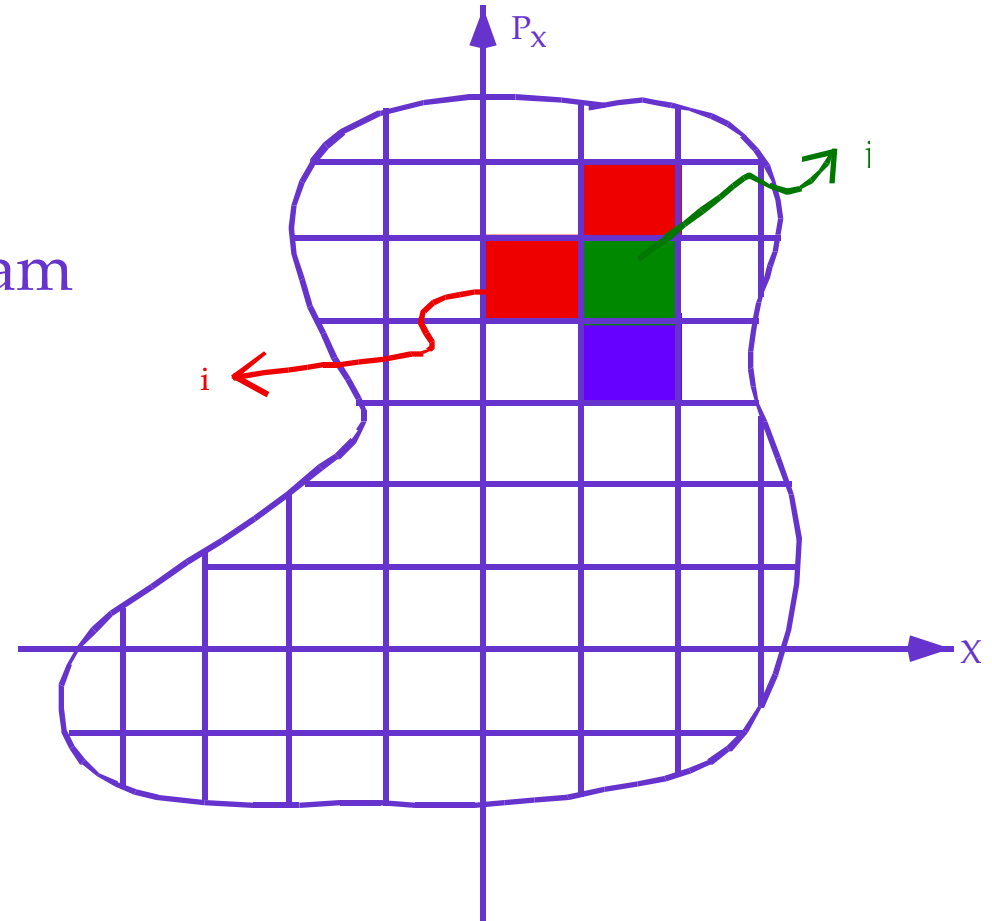
- Energy in a Beam

$$E_b \sim \sum_{i=1}^N \left[p_i^2 c^2 + m_i^2 c^4 \right]^{1/2}$$

- Entropy & Information in a Beam

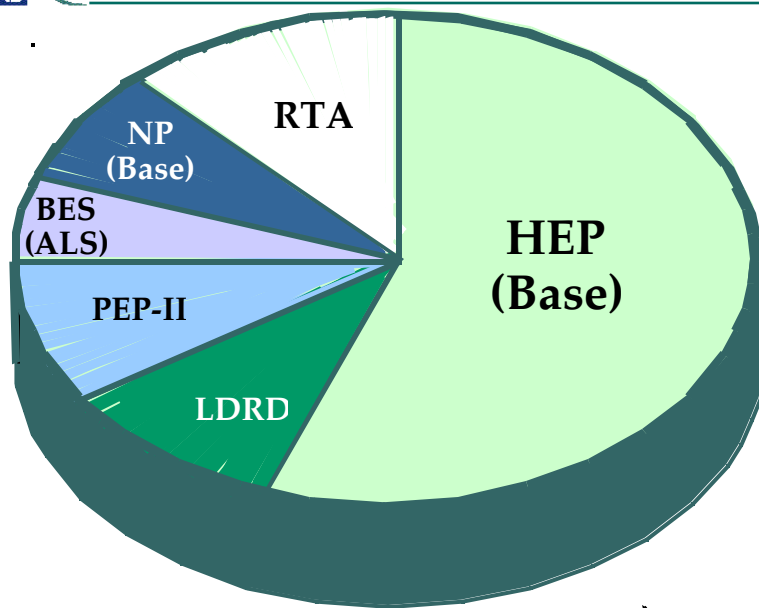
$$S_b \sim \sum_{i=1}^N n_i \ln(n_i) - 1$$

Phase Space in Rest Frame





CBP Budget : FY 1997



Operating:

~4,000 k\$

Equipment:

~250 k\$

↑
Total
CBP Funding

BES (ALS):

NP(Base):

PEP-II:

RTA :

LDRD:

RF and Beam Control in the Advanced Light Source

Phase Space Cooling of Heavy Ion Beams in RHIC (BNL)

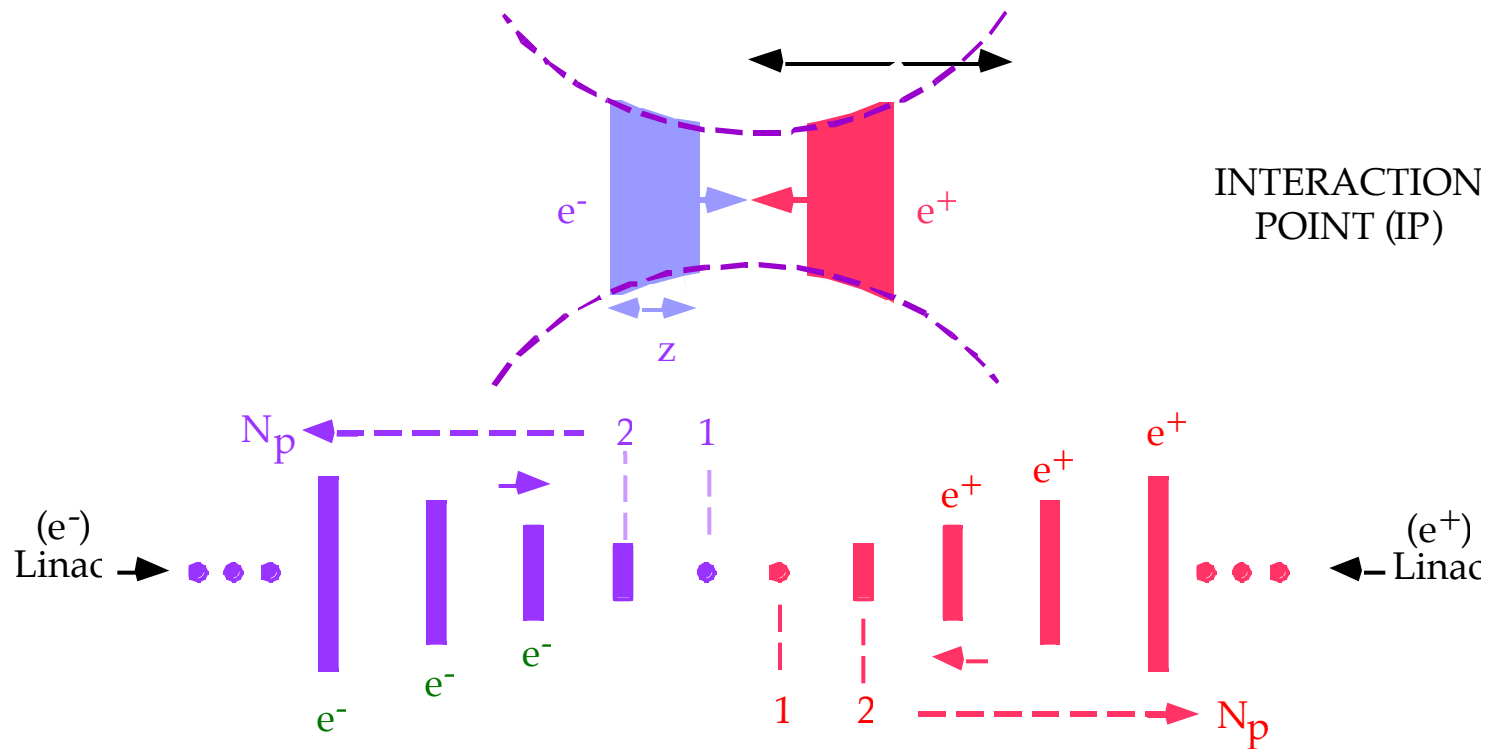
Asymmetric B-Factory at SLAC (SLAC-LBNL-LLNL)

Relativistic-Klystron Two-beam Accelerator

Laboratory Directed Research and Development



CLASSICAL COLLIDER PARADIGM



$$\text{LUMINOSITY : } L = \frac{f N^2}{4 y^2 R} \quad (f = N_p f_{\text{rep}})$$

$$\text{AVERAGE POWER : } P_b = 2 mc^2 N f = P_w$$



Classical Collider Scalings

$$L = \frac{fN^2}{4 \gamma^{*2} R} H$$

$$= \frac{0.43 r_e^2}{z \gamma^{*2}} \frac{N}{1+R}$$

$$N \sim 10^8 \hat{x} \hat{x}^{1/2} \frac{1+R}{R} \hat{x}^{3/2}$$

$$B \sim 0.5 \frac{\hat{x}^2}{1 + (1.5 \hat{x})^{2/3}}$$

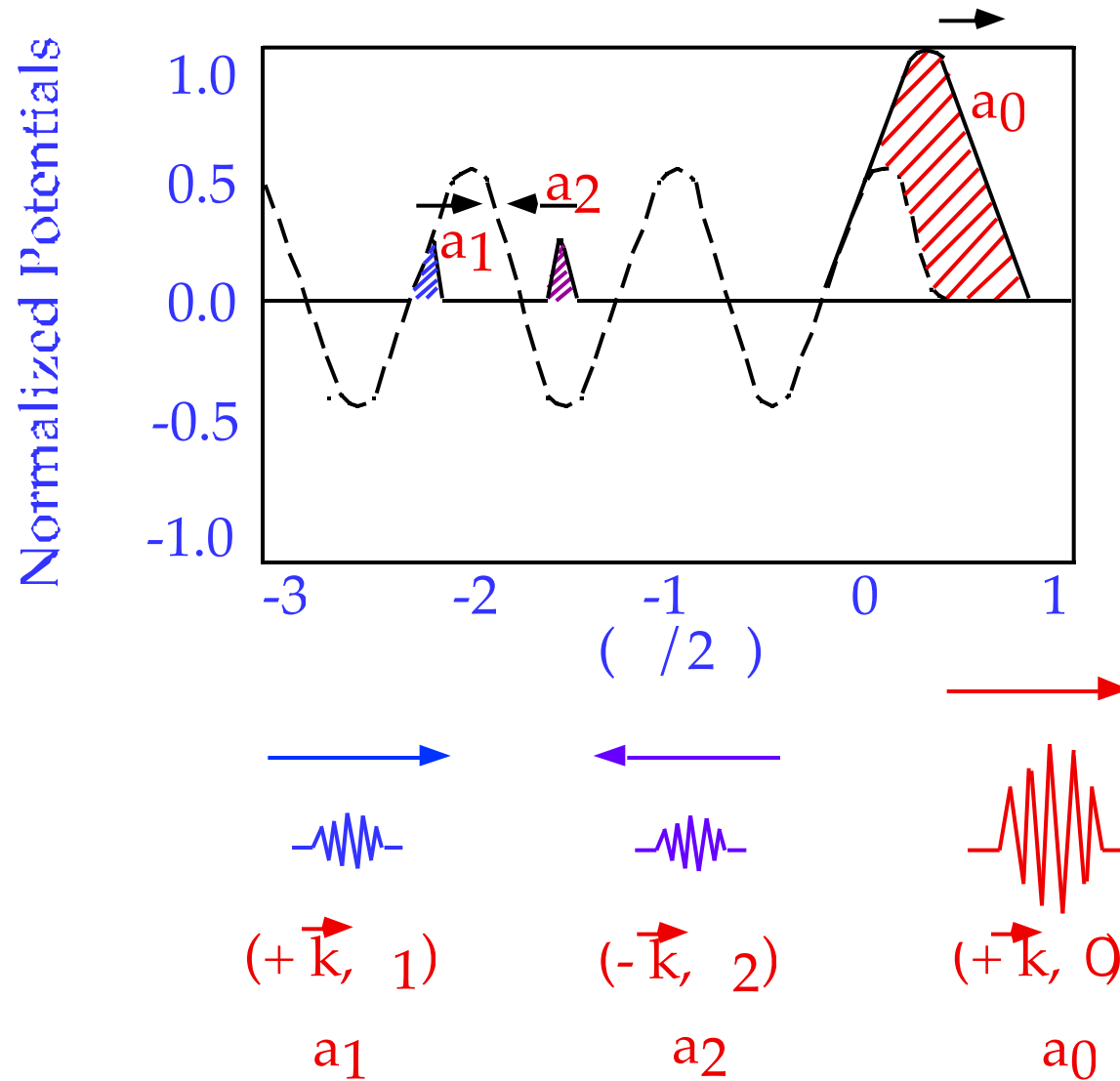
$$f \sim 2.6 \times 10^7 \frac{R}{(1+R)^2} \frac{1}{\gamma^{*2}} \frac{1}{2} \hat{L}$$

$$P_b \sim 2 \times 10^9 \frac{\hat{L}}{(1+R)} \frac{1}{\gamma^{*1/2}} \hat{x} \hat{x}^{1/2}$$

$$D_Y \sim 0.6 R^{3/2} \hat{x} \hat{x}^{-1/2}$$

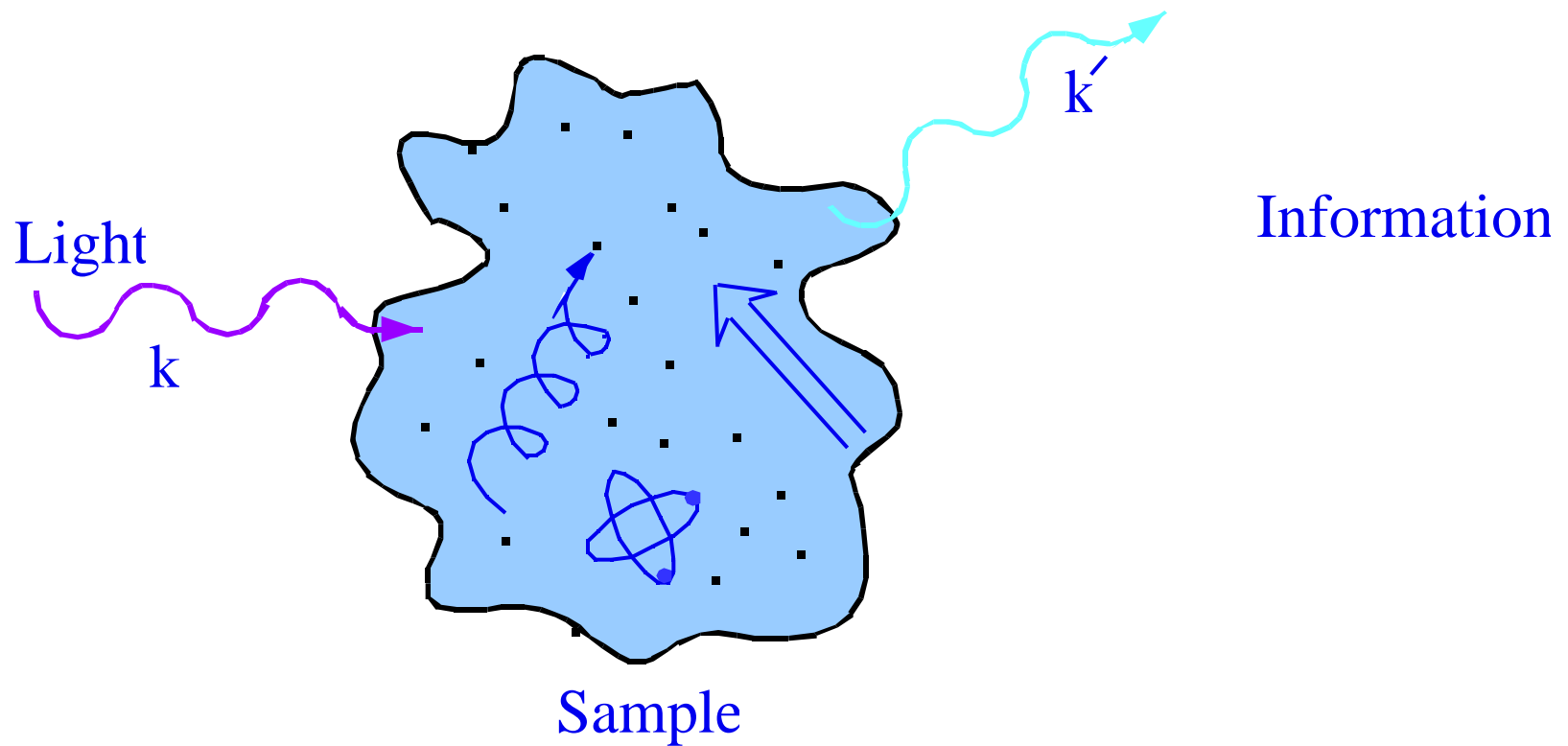


Colliding Pulse Injection & Laser Wake Acceleration





Condensed Matter, Biology, etc.





Consolidation of Experimental Infrastructure & Opportunities

- The Beam Test Facility provides access to the 50 MeV electron beam from the ALS injector linac transferred via a magnetic transport line into a specially shielded experimental vault, for experimental R&D in beam physics.
- Table-Top Terawatt laser already built via Laboratory Directed Research & Development funds. Another one already exists at the L'OASIS Laboratory.
- Components & plasma tests at the CBP L'OASIS Laboratory & the Lambertson Beam Electrodynamics Laboratory.
- Experimental plan fully developed.
- Local expertise in beam physics, plasma physics, high power & short pulse lasers, laser guiding, rf control & quantum optics is complete.



Consolidation of Experimental Infrastructure & Opportunities

(con't)

The CBP facilities provide a highly cost-effective program in frontier accelerator competitive & complementary to other international and national efforts. definitive results in the next years on the following:

- Focussing of relativistic beams by plasmas.
- Demonstration of guiding & confining high field gradients over long distances (1 GeV/m over a macroscopic length of a few cm to a meter).
- Detailed field & phase space dynamics mapping over the "confined c."
- Feasibility & utility of Femtosecond Thomson x-ray source
- Feasibility & utility of Storage Ring Femtosecond x-ray source.
- Optical Stochastic Cooling.



Don't Bet on It

from Reader's Digest

AT THE END of every December, when Father Time's odometer is ready to click in another year, experts seem compelled to forecast what the coming year will bring. Economists read their econometric entrails and predict hard times or happy days accordingly; psychics announce that this is the year the San Andreas fault will pitch California into the sea. Well, before you believe any of this year's predictions, consider these vintage prognostications:

—Octave Chanute, aviation pioneer, in 1904: "The (flying) machine will eventually be fast; they will be used in sport, but they are not to be thought of as commercial carriers."

—*The Literary Digest*, 1889: "The ordinary 'horseless carriage' is at present a luxury for the wealthy; and although its price will probably fall in the future, it will never come into as common use as the bicycle."

—Thomas Edison, on electricity in the home: "Just as certain as death, [George] Westinghouse will kill a customer within six months after he puts in a system of any size."

—Lt. Joseph C. Ives, Corps of Topographical Engineers, 1861, on the Grand Canyon: "[It] is, of course, altogether valueless Ours has been the first, and will doubtless be the last, party of whites to visit this profitless locality."

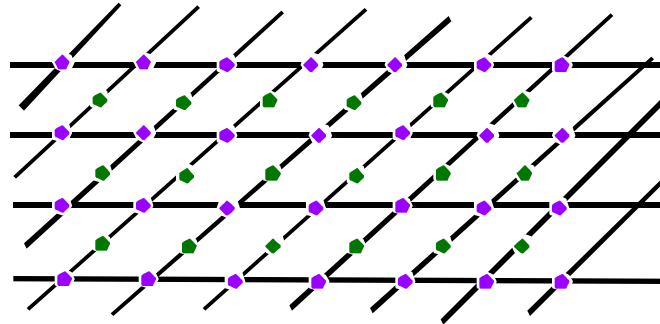
—Science Digest, August 1948: "Landing and moving around on the moon offers so many serious problems for human beings that it may take science another 200 years to lick them."

—Physicist and mathematician Lord Kelvin (1824-1907), who seemed to have a corner on the wrongheaded oneliner in his day: "X-rays are a hoax." "Aircraft flight is impossible." "Radio has no future."

—Paul Dickson, *The Future File* (Rawson Associates)



DYNAMICS ON A SURFACE



Lattice vibrations and 'Phonon'
spectrum characterized by Debye
time-scale :

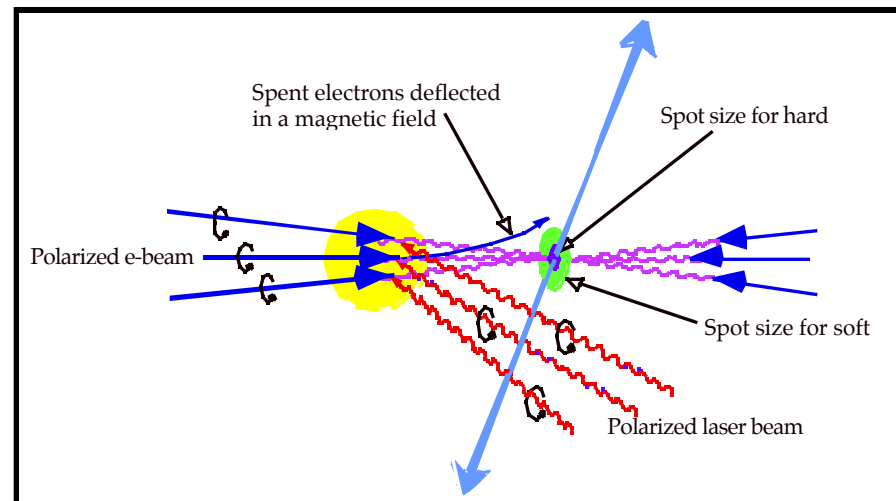
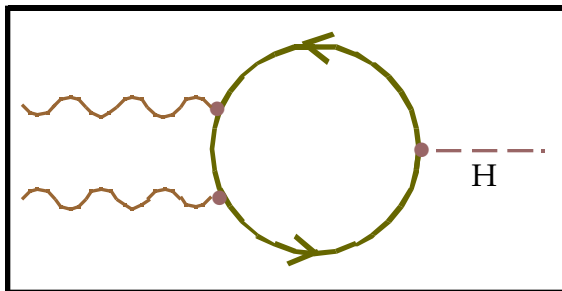
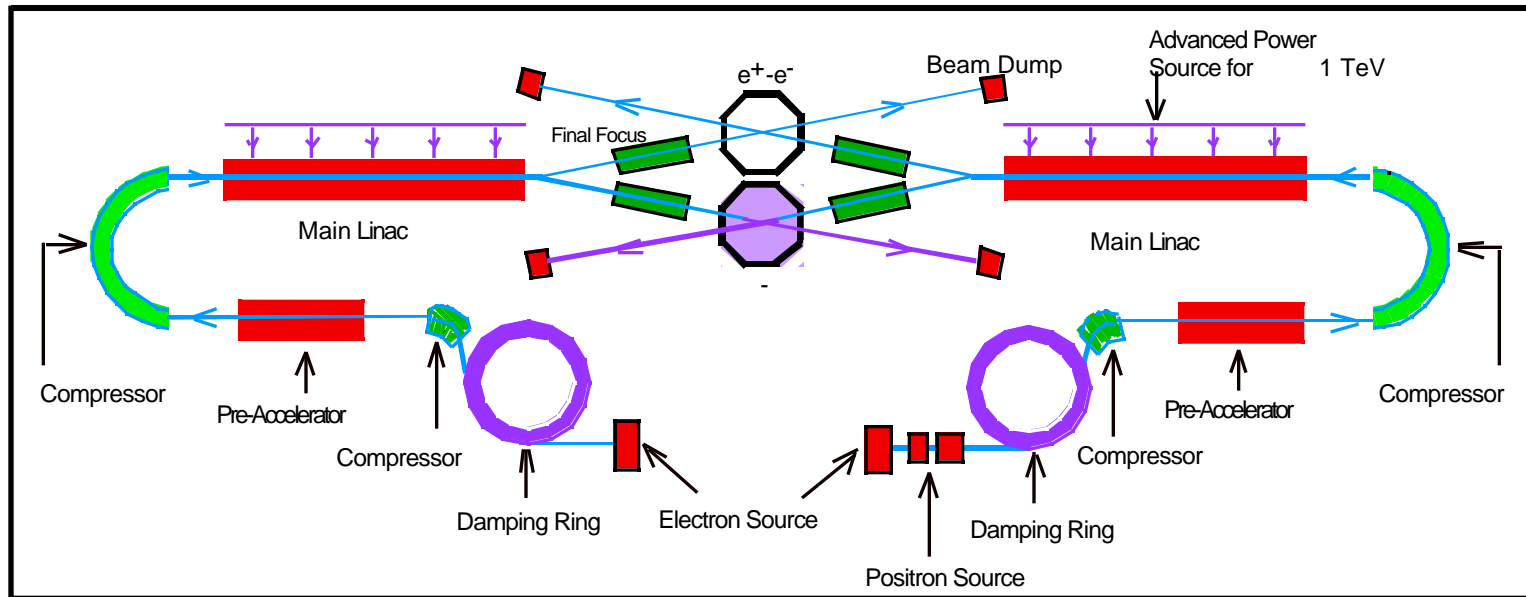
Lattice relaxation time :

Phonons $\rightarrow h$ kT \leftarrow Thermal Bath

$$\tau = \hbar / kT \sim 100 \text{ fs @ room temp.}$$

e.g. PHASE TRANSITIONS like surface melting
etc. take place on these 1 - 100 fs time-scale.
EXTREMELY VALUABLE INFORMATION for
SEMICONDUCTOR PHYSICS. e.g. Silicon

e^+e^- Energy Frontier





Educational Activities

- US Accelerator Schools :
 - UC San Diego, Winter '95-'96 (Beam Electrodynamics Group)
 - University of Maryland, Fall '96 (J. Byrd)
 - US-Japan Accelerator School, '96 (J. Byrd)
 - UC Berkeley, Winter '97 (J. Wurtele, K.J. Kim, J. Corlett, J. Byrd, S. Chattopadhyay)
- United Nations UNESCO School on Synchrotron Radiation, March '96 (K.-J. Kim)
- Regular graduate courses at UCB (Wurtele, Kim, Chattopadhyay)
- Graduate Seminar Class at UCLA
- Biweekly Center for Beam Physics Seminars
- Books generated: E. Forest. " Storage Ring Dynamics: A New Formalism"
K.J. Kim, "Synchrotron Radiation", in preparation.
- Total number of students involved in program :
 - 11 graduate and undergraduate students altogether



Effort Breakdown

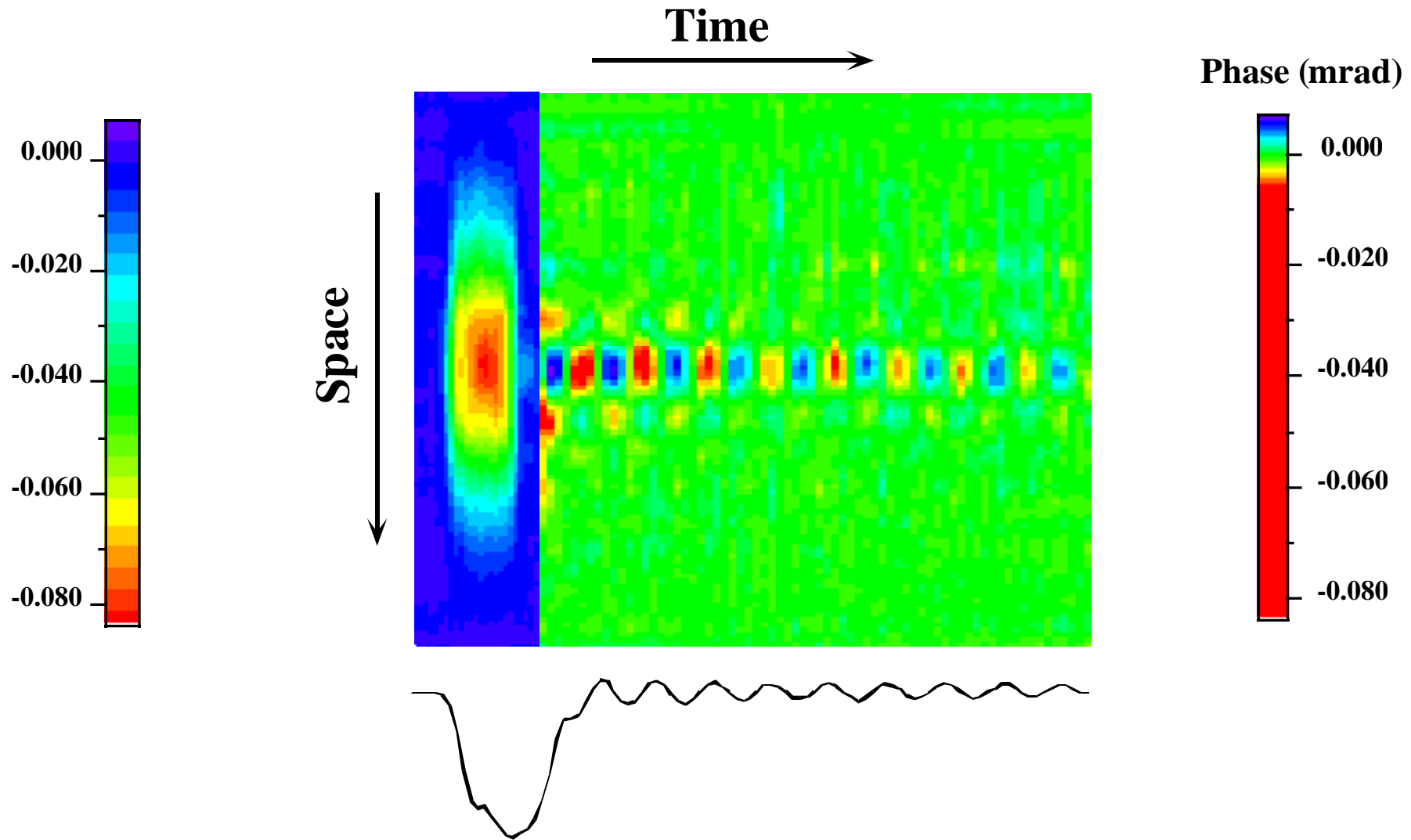
FTEs

- 2.5 PEP-II
 - 1.5 Radiation Sources/FELs
 - 4 RF Power Source/RTA
 - 7 Accelerator Theory, Advanced Accelerator Methods, Lepton Colliders & Experimental Program
 - 1 ALS RF, Feedback & Instabilities
 - 1.5 Beam Cooling for RHIC
 - 2.5 Technical Associates
 - 4 Administration
 - 2 Students
-

Total : 26 (15 from HEP Base)



Electron density oscillation





Experimental Facilities

- Beam Test Facility (BTF) at the ALS
- Lambertson Beam Electrodynamics Laboratory
- l'OASIS (Laser, Optics & Accelerator Systems Integrated Studies)
- - New facility under preparation
- Relativistic Two-beam Accelerator (RTA) Facility, Building 58

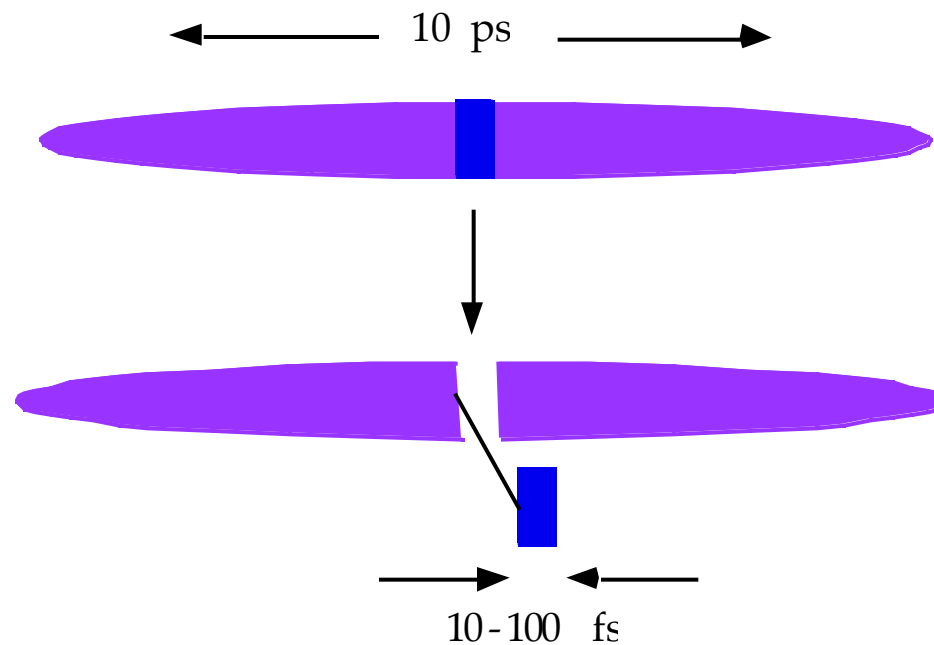


Experimental Program

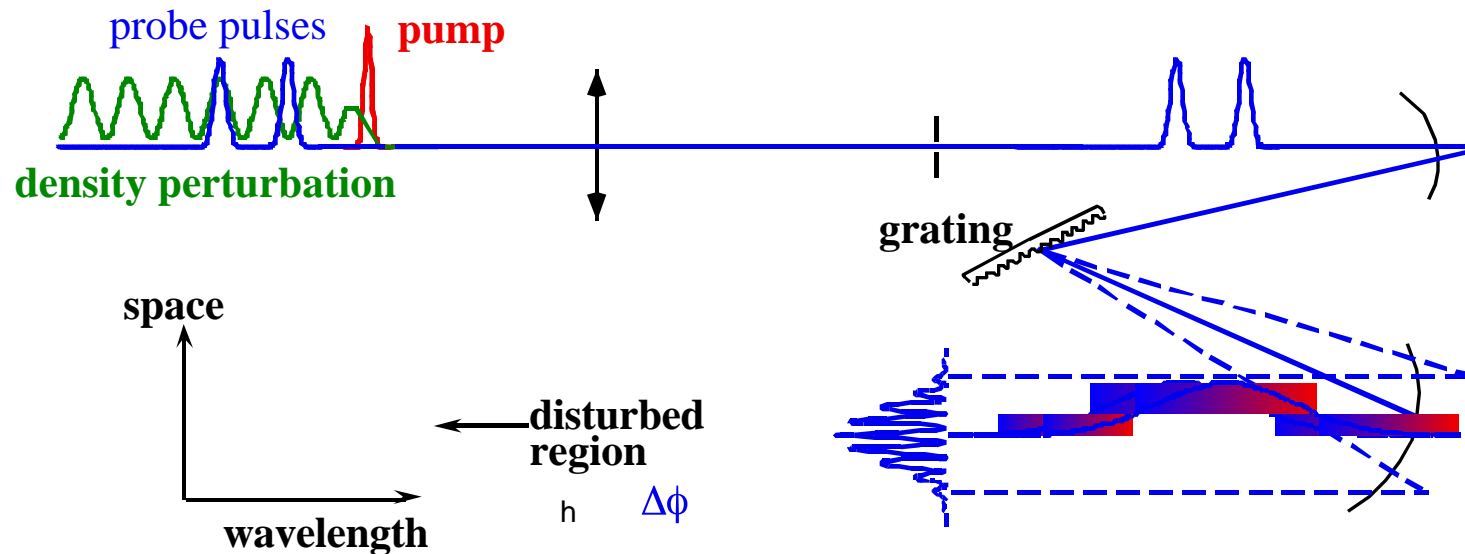
- Beam Focussing
- Laser-Electron Beam Interaction
- Novel RF Structures
- Novel Diagnostic Techniques
- Laser Acceleration :
 - Generation of high gradients over long distances by laser-plasma wakefields (with guiding).
 - Systematic mapping of field configuration & dynamic phase-space acceptance of acceleration channel by high quality, spectrally pure beam.
- Optical Cooling & THz Signal Processing
- THz power sources



Femtosecond 'Tickle' and Slicing of Picosecond Electron Beams



Frequency domain interferometry



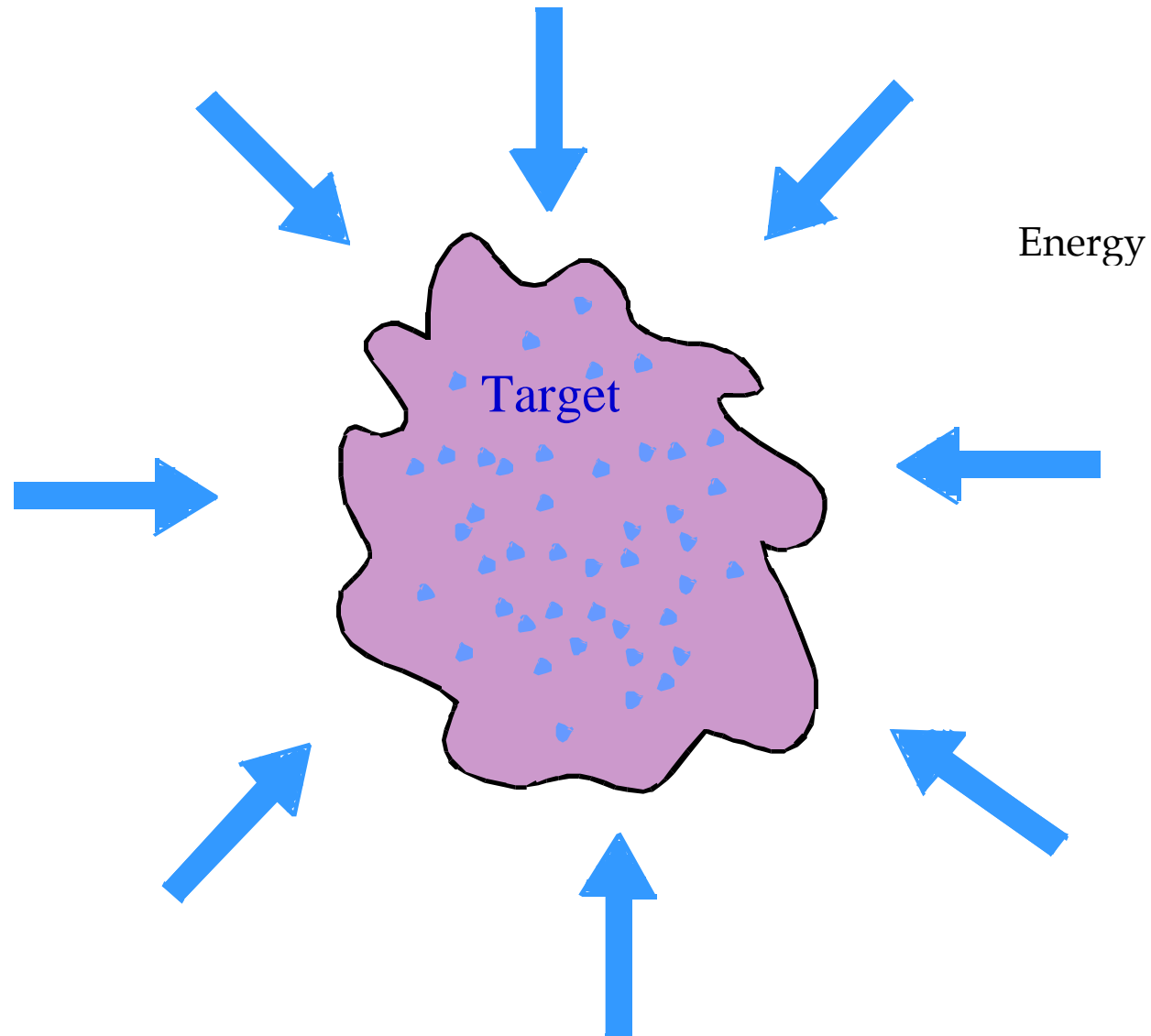
$$I(\omega) = 4 I_0(\omega) \cos^2\{(\omega\Delta t + \Delta\phi) / 2\}$$

- One dimension interferometry (spectrometer slit)
- A very good signal/noise ratio (a full system of fringes for each point of the object)
- $\Delta\phi_{\min} \leq 1 \text{ mrad } (10^{-4} \text{ fringe})$

J. P. Geindre et al, Opt. Lett. 19, 1997 (1994)



Fusion



Harmonic Generation

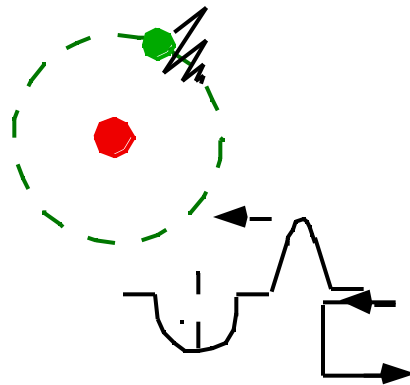
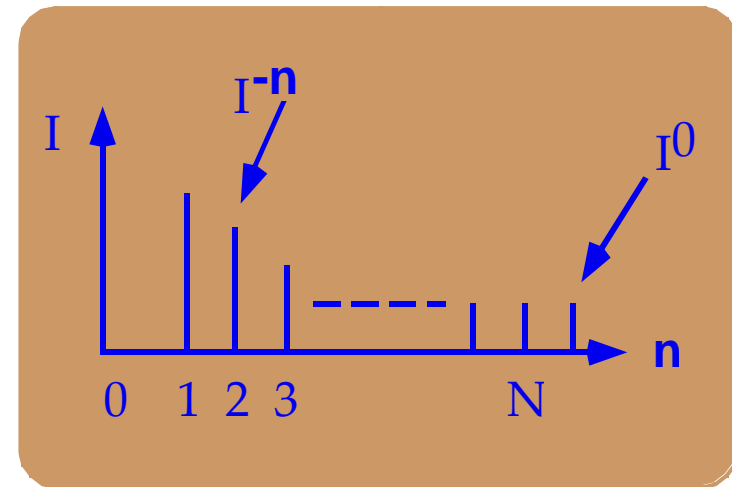
SHORT PULSE X-RAY SOURCES : GENERATION MECHANISMS

Coherent : directional

Short pulse

100 \AA for $I > 10^{15} \text{ W / cm}^2$

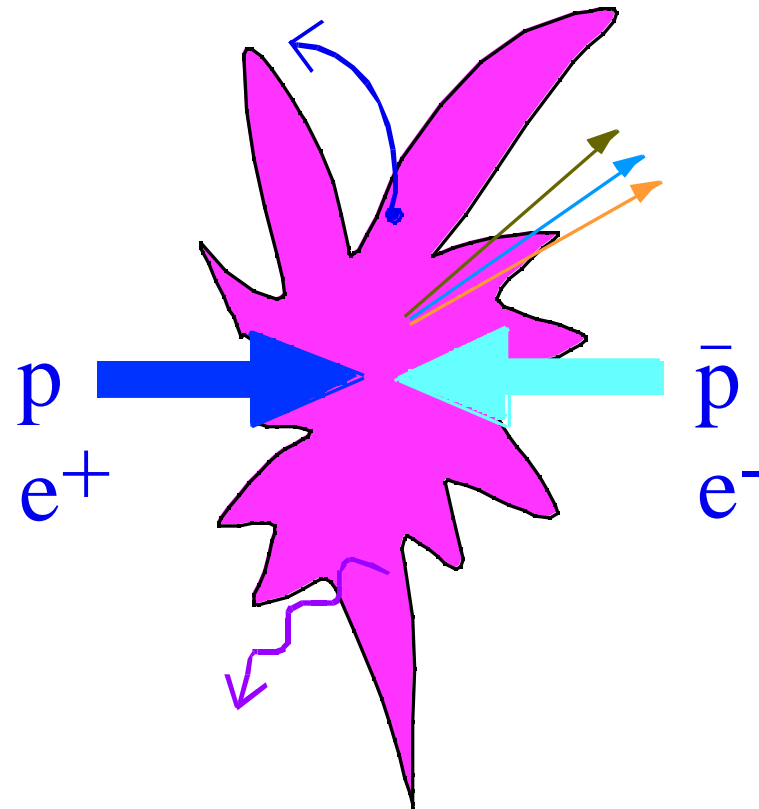
Inefficient ? $10^{-6} - 10^{-11}$





High Energy Physics

(i.e. Particle & Nuclear Physics):



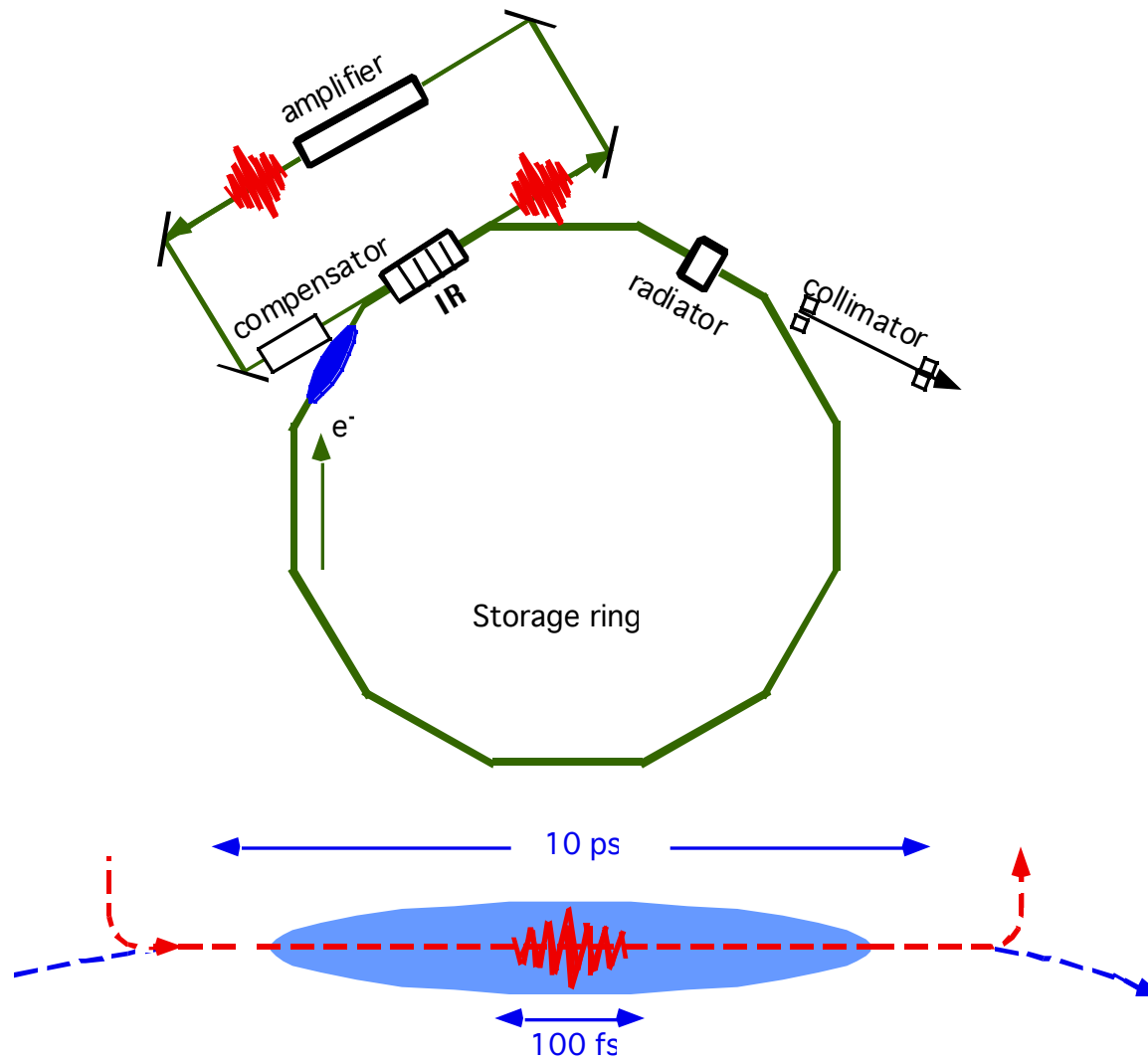
Energy
and
Information

Fireball of pure energy nucleating into matter and waves again.



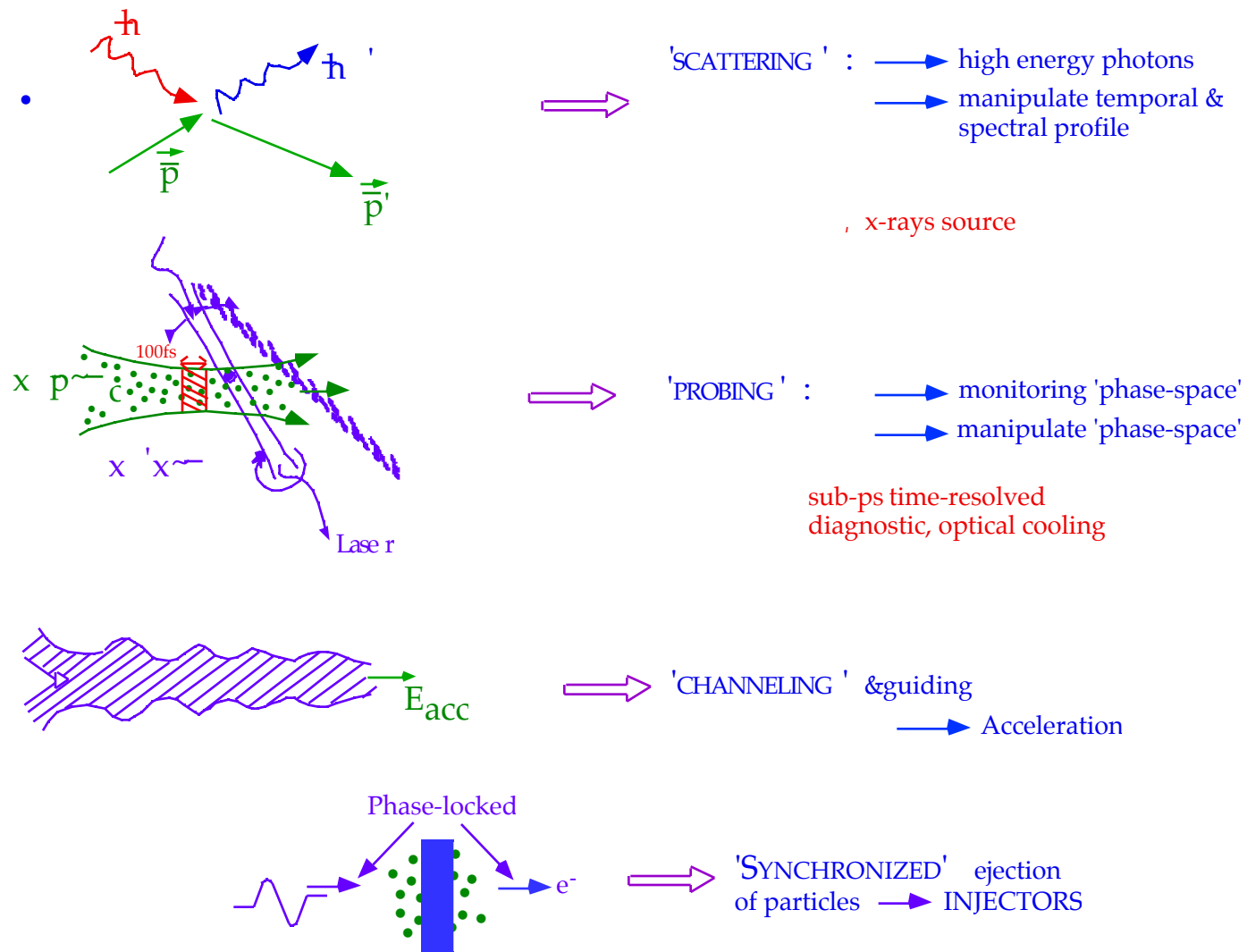
Femtosecond Slicing in a Storage Ring

Implementation in the ALS



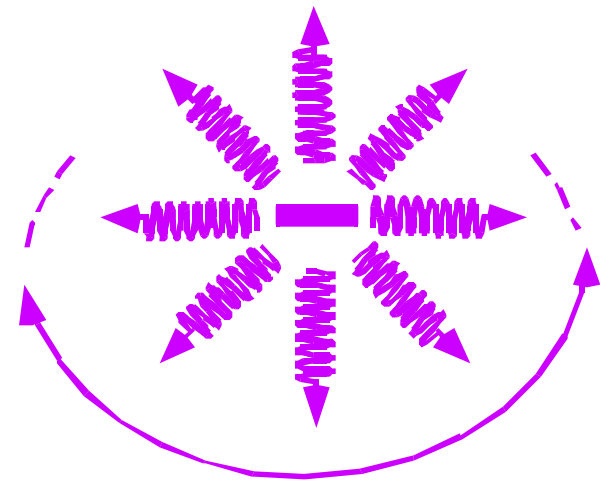


Laser-Beam Interaction



Laser produced plasma sources

- Line emission, recombination radiation and bremsstrahlung
- Incoherent but bright
- Efficient in sub-keV region \sim ps : -s ??
- Large solid angle

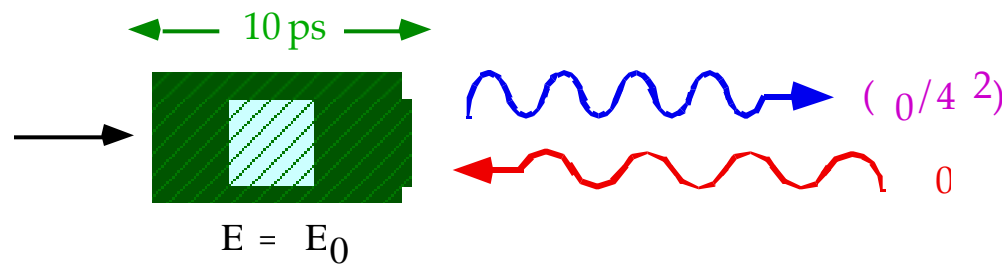


4π Solid angle



Laser scattering from electron beam

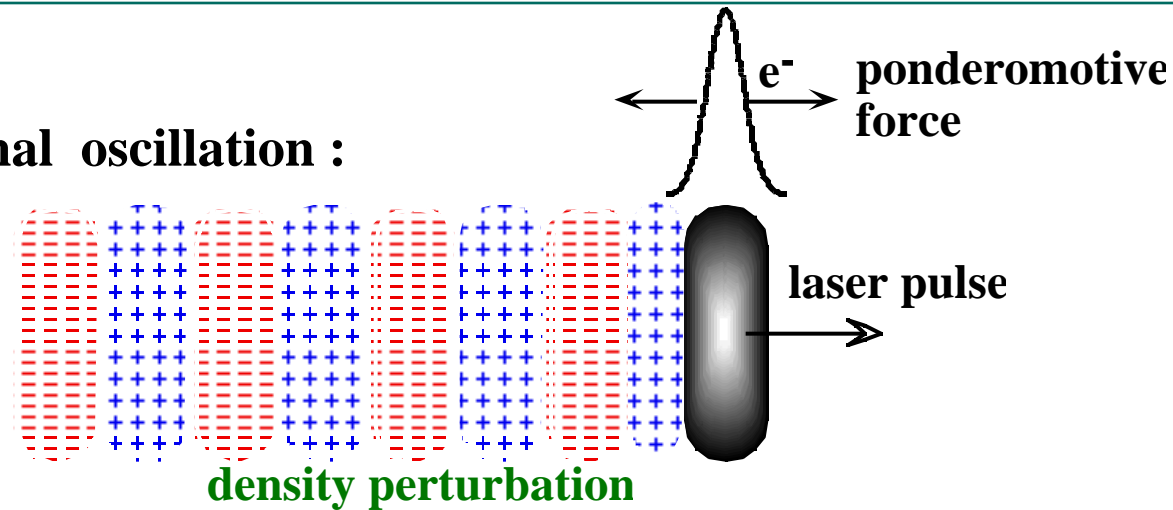
SHORT PULSE X-RAY SOURCES : GENERATION MECHANISMS



Still limited to "picosecond" time-scales :
Photon Pulse length ~ Longer of (e^-, γ) Pulse

Laser wakefield principle

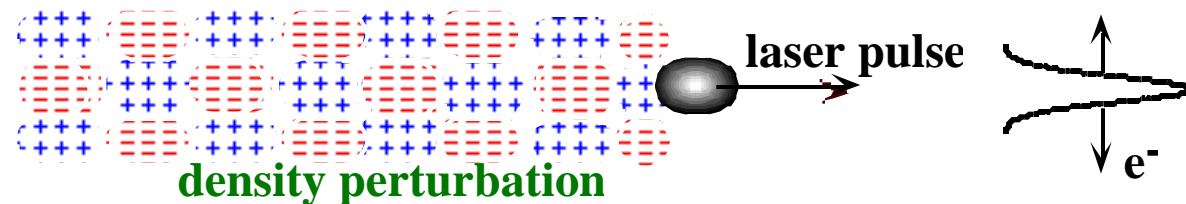
Longitudinal oscillation :



Longitudinal electric field with $v_{\phi} = v_g$ laser

Can be used for particles acceleration

Transverse oscillation :



Transverse electric field with $v_{\phi} = 0$



Memoranda of Collaboration and MOUs

- PEP-II (SLAC/LBL/LLNL)
- SLAC/LBL/LLNL on Next Linear Collider (NLC) ZDR
- CERN-CLIC/LBNL-CBP on Two-Beam Accelerator
- UC Davis/LBNL/SLAC - ATRI on Microwave Technology
- UC Davis-NEG/LBNL-CBP - AXF photocathode gun at 11.4 GHz
- Peking University-SCRF Dept./LBNL-CBP : on Superconducting RF photocathode development
- Kyoto University/LBNL-CBP : General Beam Physics
- Jefferson Lab/LBNL : FELs
- BNL-RHIC/LBNL-CBP : Beam Cooling in RHIC

Informal collaboration with MIT on 17.4 GHz electron gun



POTENTIAL:

Memoranda of Collaboration and MOUs

- BINP-LBNL - Gamma-Gamma Collider
- LLNL-LBNL - High Average Power Lasers for HEP
- LBNL-BNL-FNAL - Muon Collider Studies
- LBNL-BNL-FNAL - LHC Studies
- CESTA-LBNL - Collaboration on TBA Studies



Mission

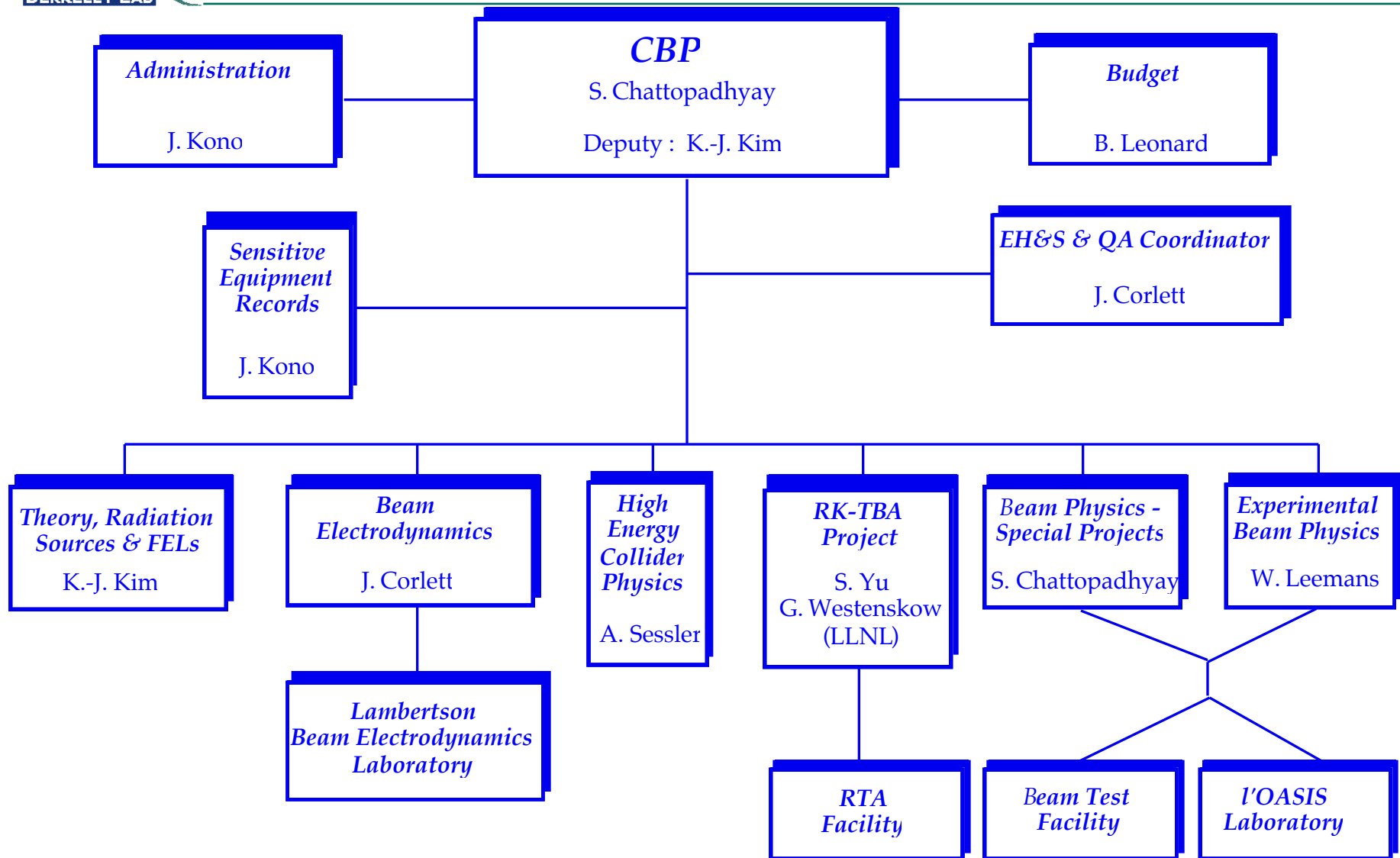
- Research and Development for the production, manipulation, storage, and control of particle and photon beams as applied to fundamental studies in natural sciences, energy sciences, industry and commerce.

High Energy Physics, Nuclear Physics, Material and Chemical Sciences, Life Sciences, Information & Power Beaming, Energy Production, Information Storage and Manipulation (computing), . . .

- Education of students, would-be practitioners and other segments of the community.



CENTER FOR BEAM PHYSICS





Outline

- BEAMS : mais, qu'est-ce que c'est ?
- Mission
- Scope
- Research Output : Comments
- Effort Breakdown
- Budget
- Staff
- Organization
- Memoranda of Collaboration & MOUs
- Educational Activities
- Professional Services
- Sponsored Conferences & Workshops
- Awards & Honors
- Research Program



Professional Services

- APS President-Elect : A. Sessler
- APS/Division of Physics of Beams Executive Committee : S. Chattopadhyay
- ICFA Subcommittees : K.-J. Kim (Radiation Sources)
S. Chattopadhyay (New Methods & Techniques)
- Editorship of *Particle Accelerators* : S. Chattopadhyay, Editor-in-Chief,
Western Hemisphere
- Advisory and Program Committee of International and National Particle
Accelerator, LINAC and FEL Conferences
- Snowmass'96 : Accelerator Subgroup Convener (J. Wurtele)
Advanced Accelerator Technique Group Leader (S. Chattopadhyay)



Radiation Sources

Characterisitics

- Wavelength coverage
- Spectrum and spectral brilliance
- Coherence
- Pulse length and structure - average power
- Other features, e.g. polarization, etc.



Research Output : Comments con't #1

Contribution specific to Radiation Sources :

- Conception, design, construction & commissioning of the Advanced Light Source (ALS).
- Collaborative work at PLS (Korea), Sincrotron Trieste (Italy), SRRC (Taiwan), SLS (Switzerland), SPring-8, . . .
- R & D on FELs & Novel Radiation Sources. (CDRL @ LBL, LCLS @ SLAC, CEBAF IR/UV FEL, DESY / TESLA FEL, National Collaboration on SASE/FEL Demonstration, Power Beaming, Femtosecond x-ray sources, etc.).

Research Output.....con't



con't.....

Research Output : Comments

Significantly creative contributions :

- PEP-II : new program launched in US-HEP based on asymmetric collider rings (J. Corlett, R. Rimmer)
- Gamma-Gamma IR in Linear Colliders (K-J. Kimtalk)
- RTA Power source beyond 1 TeV e^+e^- collisions (S. Yu and G. Westenskow's talk)
- Contributions to ALS
- Femtosecond x-ray sources and Advanced Laser-Beam Techniques (talks by W. Leemans and S. Zholents)



Research Output : Comments

- Beam Test Facility (BTF): Advanced Experimental Facility for carrying out forefront R&D in advanced accelerator concepts in support of colliders and radiation sources of the future (W. Leemans talk)
- New facility under preparation: l'OASIS (Laser-Plasma, THz & Quantum Optics for high energy physics & radiation source studies)
- Integrated with National Effort on US-CERN collaboration on the LHC & member of the International Collaboration on Linear colliders via Interlaboratory MOU. Integrated with national Effort on Muon Colliders
- Consolidation of expertise and resources in high power (Terawatt), short pulse lasers, plasmas, electron beams, quantum optics and microwaves towards advanced research in collider physics and synchrotron radiation sources



Research Output : Comments

History of Contributions to High Energy Physics :

- FNAL (p source, cooling) ; permanent magnet storage ring for antiproton accumulation
- SSC 1980-84 : Snowmass studies, etc.
1984-88 : Central Design Group
1988-93 : Consulting + magnets + detailee, etc.
- PEP-II : initiated & now funded
- LHC/NLC : continuing
- Advanced accelerator concepts & beam physics experimental program : continuing



Research Output : Comments

- Publications
- Many advanced tools: state-of-the-art codes developed and shared with community towards collider and SR source conception and design e.g., codes and methodologies for nonlinear dynamics in storage rings based on modern analytical and numerical algorithms using Lie - and Differential-algebraic techniques, symplectic integration, etc. Complete set of codes already used by other labs (CERN, SSC /LHC, SLAC, BNL, KEK, FNAL, DESY, etc) : TRACY-II, THOR, DAPASCAL, Six Track, ZAP, ABCI, MOSES.
- Large student participation and training



- Large student participation & training
- Publications : many
- Leading contributions to initiatives in HEP :
 - PEP-II : new program launched in US-HEP
 - Gamma-Gamma IR in Linear Colliders
- General contributions to High Energy Physics :
 - FNAL (\bar{p} source, cooling) ; permanent magnet storage ring for antiproton accumulation
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- New facility under preparation : L'OASIS (Laser-Plasma, THz & Quantum Optics for high energy physics & radiation source studies).
- Industrial Collaboration : Haimson Research, Inc. on advanced accelerator rf development. Positive light on laser development.
- Integrated with National Effort on US-CERN collaboration on the LHC & member of the International Collaboration on Linear Colliders via Interlaboratory MOU. Integrated with National Effort on Muon Colliders.
 - Consolidation of expertise & resources in high power (Terawatt), short pulse lasers, plasmas, electron beams, quantum optics and microwaves towards advanced research in collider physics and synchrotron radiation sources.



Research Program

Current Activities & Future Opportunities

- High Energy Collider Frontier:

Hadrons & Heavy Ions :

- TeV*, LHC
- RHIC

Leptons :

- NLC: e^+e^- , Gamma-Gamma (talks by K.-J. Kim, J. Byrd)
- Relativistic Klystron Two Beam Accelerator (talks by S. Yu & G. Westenskow)
- PEP-II B-Factory (talks by J. Corlett, R. Rimmer, W. Barry)
- Muon Collider Studies (W. Turner & W.-H. Cheng)

- Radiation Sources :

- Fourth Generation Sources & FELs (talks by Kim, Leemans, Zholents & Xie)
- Power Beaming (talk by Kim)

- Advanced Concepts & Technologies:

- Experimental Program (talks by Leemans, Govil, Volfbeyn & Zholents)
(Laser acceleration, Plasma Focussing, Femtosecond x-ray source, ... etc.)
- New Thrust: Laser Manipulation of Beams



Scope

- The Center is involved in:
 - Conception, design, construction and commissioning of high energy colliders & synchrotron radiation sources (including FELs)
 - Beam physics R & D for advanced acceleration & radiation methods
 - Detailed measurements & proof-of-principle experiments in its four major facilities — the [Lambertson Beam Electrodynamics Laboratory](#), the [CBP/OASIS Laboratory](#), the [Beam Test Facility at the ALS](#) & the [RTA facility](#).
- The Center continues to provide core accelerator physics support for the [PEP-II](#), [LHC/NLC](#) studies, some aspects of the [Advanced Light Source \(ALS\)](#), and has major collaborations with [SLAC](#), [LLNL](#), [BNL](#), [FNAL](#), [Jefferson Lab](#), [CERN](#), [Stanford University](#), [University of California at Davis](#) and [University of California at Berkeley](#), [Kyoto University](#), [Peking University](#),....



Scope

- Significant benefit is derived from existing accelerator programs & infrastructure, supported by various divisions of DOE.
 - BES/ALS for BTF
 - HEP
 - Fusion for RK-TBA
 - NP for Beam Cooling



SHORT PULSE X-RAY SOURCES : GENERATION MECHANISMS

- Laser produced plasma sources
- Harmonic Generation
- Bunch rotation in a storage ring
- Femtosecond slicing in a storage ring
- Laser scattering from electron beam



Sponsored Conferences and Workshops

- Mini Workshop on Laser Acceleration — 1995
- ICFA Nonlinear Dynamics Workshop — 1996
@ Arcidosso, Italy together with SLAC and UCLA
- Advanced Accelerator Workshop — 1996 @ Lake Tahoe
(sponsored by DOE/HEP)
- Muon Collider Workshop — February, 1997 @ LBNL
- Muon Collider Workshop — May, 1997 @ Orcas Island, British Columbia
- ICFA Workshop on Quantum Aspects of Beam Physics, to be held January 1998 in Monterey.
- ICFA Nonlinear Dynamics Workshop — 1998
@ Arcidosso, Italy together with SLAC and UCLA



Staff Roster

Scientists & Engineers :

ARCHAMBAULT, Leon
BARRY, Walter
*BYRD, John
CHATTOPADHYAY, Swapan
CORLETT, John
DOUGHERTY, Jim
FURMAN, Miguel
GOLDBERG, David
KIM, Kwang-Je
LEEMANS, Wim
LEONARD, Bud
LOZANO, David
RIMMER, Robert
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HARTEMANN, Fred
HOUCK, Tim
LUHMANN, Nevill
PALMER, Robert
SCHACHINGER, Lindsay
SCHOENLEIN, Robert
SHANK, Charles
TAJIMA, Toshiki
van BIBBER, Karl
VANECEK, David
WESTENSKOW, Glen
ZISMAN, Michael

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JOHNSON, C., CERN
KISHIMOTO, Y.
KOGA, J.
KOSTA, S., CAT
KRISHNAGOPAL, S., CAT
ORLOV, Y. Cornell
RYNE, R., LANL
TELNOV, V., BINP
YOKOYA, K. KEK

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FERNANDEZ, Susana
GOVIL, Richa
GUO, Kang-Zhu
IRWIN, Mike
LEE, Peter
LIDIA, Steve
LIE, James
PONCE-MARQUES, David
SCHROEDER, Carl
VOLFBEYN, Paul
WHEELER, Susan

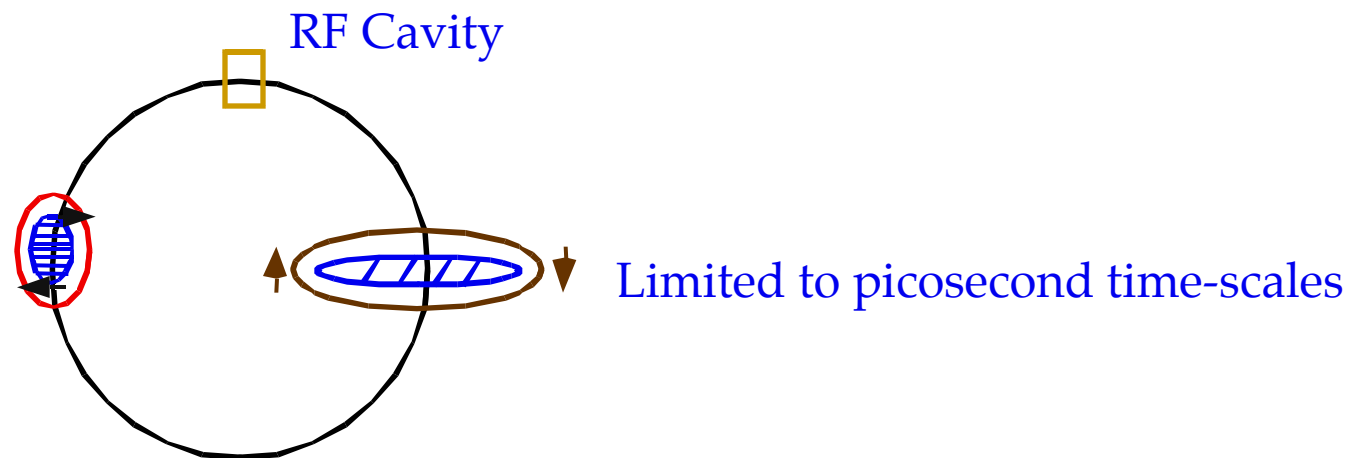
Participating Guests

GARREN, Alper
GHIORSO, Albert
LAMBERTSON, Glen
PETERSON, Jack
SELPH, Frank
VOELKER, Ferdinand



- STORAGE RINGS :

Rapid bunch rotation in a storage ring used as a synchrotron light source.



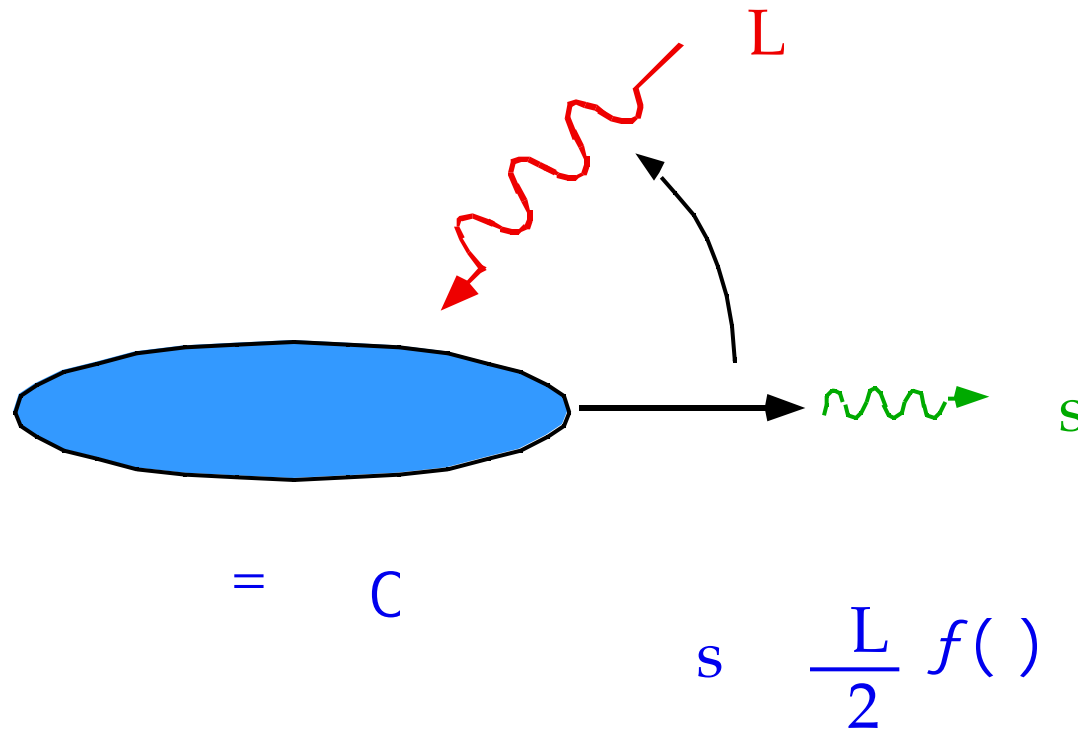


SNOWMASS '97

CURRENT STATUS OF 5 TeV COLLIDER RESEARCH

<i>Technology</i>	<i>Wave-length λ</i>	<i>Potential Gradient</i>	<i>Collider Length</i>	<i>R & D</i>	<i>Technology Details</i>
SCRF	>10 cm	100 MV/m	60 km	Superconducting materials research; new superconductor; site	'Bismuthate' materials
RF	1 cm	200 MV/m	30 km	Power sources prototype, drive beam dynamics, site	30 GHz TBA
				sheet beam klystron research, site	30 GHz Tube Driven
mm-wave and THz	<3 mm	1 GV/m	< 10 km	pwr source invention, structure invention, fabrication tech.	90 GHz Dielectric 90 GHz Conducting 1 THz
Lasers & beams in plasmas & structures	<300 μ m	>10 GV/m	~ km	module prototype, rep. rating guiding, staging, beam dynamics	laser structure-based laser plasma-based beam structure-based beam plasma-based
	relevant to all the above			~10 kHz rep. rate, TW peak power lasers, IR mechanical configuration	

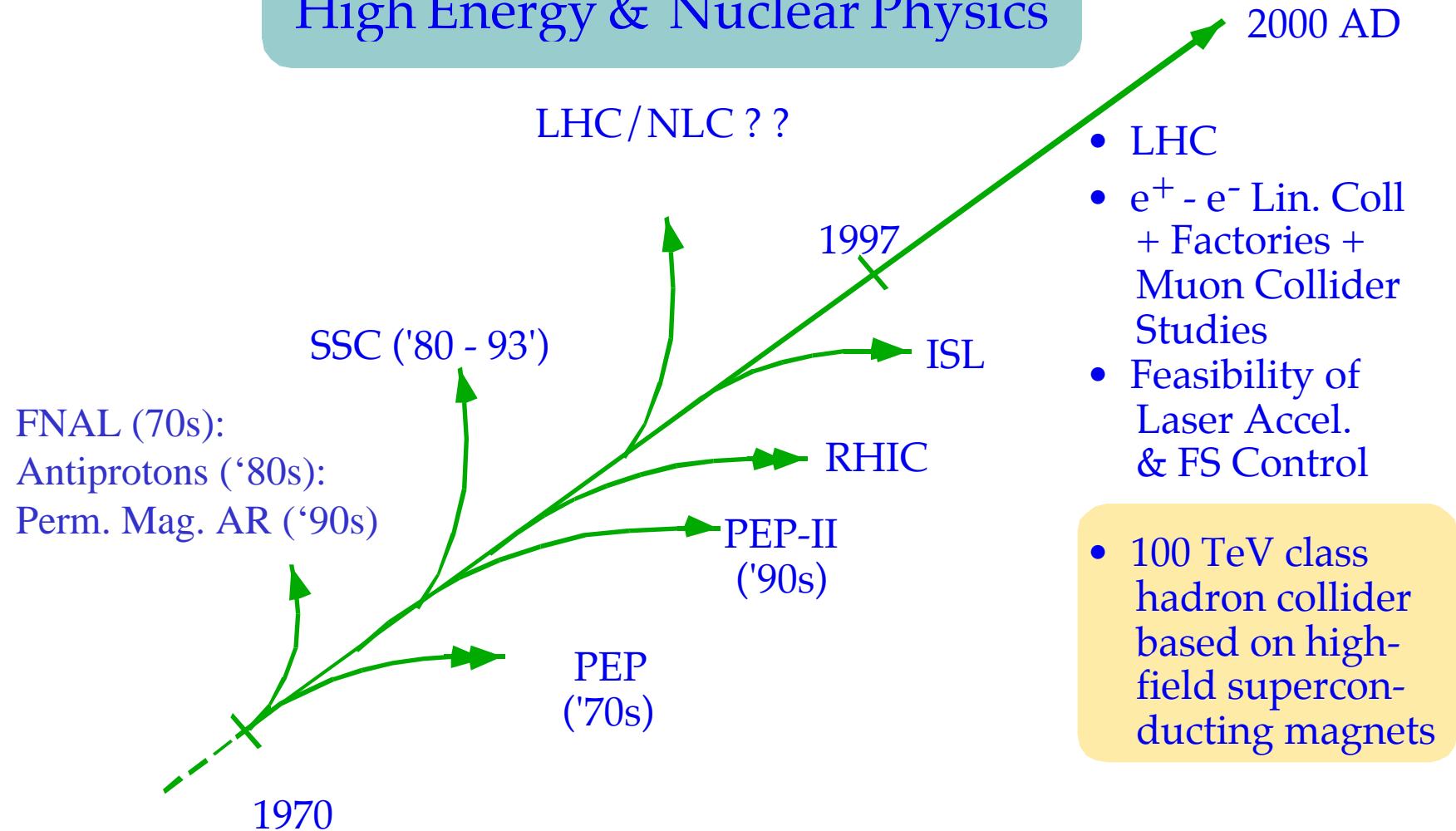
THOMSON/ COMPTON SCATTERING





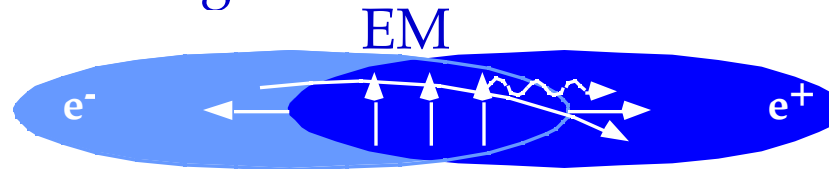
Where From ? Where To ?

High Energy & Nuclear Physics



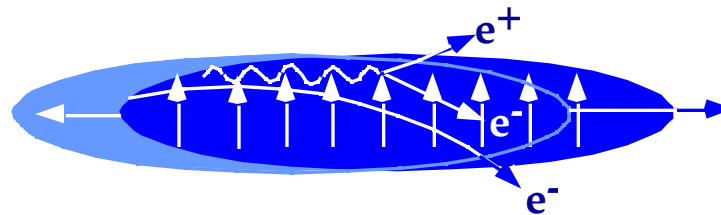
- Quantum Effects

Beamstrahlung :



Coherent Pair Creation Background :

Chen-Telnov, 1988-8



Minijets Background :

Drees-Godbole, 1991

